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The value of high performance visualization techniques for Method of Moments modeling of electromagnetic (EM) field radiation and scattering for antennas in a complex environment is demonstrated. EM visualization was performed on a Silicon Graphics IRIS 4D/320GTX workstation. This application of high performance visualization is demonstrated for the problem definition, computation and solution description phases of the method of moments technique.



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# EM Visualization on a SGI 4D Workstation

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*Abstract*

The value of high performance visualization techniques for Method of Moments modeling of electromagnetic (EM) field radiation and scattering for antennas in a complex environment is demonstrated. EM visualization was performed on a Silicon Graphics IRIS 4D/320GTX workstation. This application of high performance visualization is demonstrated for the problem definition, computation and solution description phases of the method of moments technique.

## 1.0 NEED FOR VISUALIZATION

Computational electromagnetics can be thought of as a three step process: problem definition, computation, and solution description. The drawback to using a computational electromagnetics code such as NEC-MoM (Burke and Pogio, 1981) is in the effort required at each of the three steps. Preparing the input model for NEC-MoM and evaluating the output can be an overwhelming task. Performing calculations can be exceedingly time consuming for all but the most simple structures.

To conserve computing resources, input models must be extensively validated before calculations are performed. Enormous quantities of output data are generated including currents and charges on all the wire segments, near field contours, and far fields. The goal of this effort was to demonstrate how advanced visualization techniques could be used to assist in input validation and rapid interpretation of output data.

## 2.0 VISUALIZATION TECHNIQUES

Decisions have to be made regarding how to effectively visualize the data of interest. In many cases, there were found to be several options. Often it was difficult to decide which display method would have the most utility for the final user. The products of this effort are now being used in support of ship EM design projects. This application of these tools will quantify utility.

One of the main problems encountered was in deciding how to assign color codes. Color coding is an art unto itself. It was often difficult to decide whether color coding should be done using a continuous range of colors or using a discrete set of colors.

There are three components to color. The RGB color model interprets these components as the three colors (red, green, blue) used by the CRT. By varying the amount of each color component the full range of screen colors can be achieved. The Silicon Graphics workstation has 24-bit color, with 8 bits for each component. Each component is an integer value between 0

and 255. In this manner the console is capable of displaying over 16 million different colors. Of course, it is doubtful that the human eye can distinguish all these.

Humans do not perceive colors in the same manner that the console displays them. To humans it is more intuitive to use the HSV color model (hue, saturation, and value). The HSV model is based on the intuitive appeal of the artist's tint, shade, and tone. Hue has a value between 0 and 360. Saturation and value range between 0 and 1. Algorithms exist for translating between the different color models (Foley, 1990).

At one point during this effort it was proposed that various data components could be encoded into the different components of the HSV color model. For example, for complex data the magnitude could be encoded in the hue and the phase could be encoded in the value. This idea was found to not be feasible for two reasons. First, the user becomes overwhelmed by the amount of information contained in slight variations in displayed color. Second, the color printer was totally incapable of reproducing anything but major variations in color, so one could not obtain a hard copy output of the visualization display.

For most data sets a discrete color key coding system was found to provide the most useful visualization of the data. Seven bins were chosen and the data is linearly or logarithmically assigned to the bins. The color key assignments were changed several times. A final decision was made to use colors that gave the best contrast when printed out on the color printer. Phase is displayed as a continuous range of hue, with saturation and value set to unity.

In most cases, it was found that trying to display both components (real and imaginary or magnitude and phase) of a complex data set in one image confused the user unnecessarily. A decision was made to allow the user to display complex data in side by side windows if both components needed to be viewed simultaneously.

Current data, charge data and field data are vectors. A straightforward method for displaying a vector's orientation was never developed. The current and charge vectors are defined relative to the wire's direction. User interaction indicates that the current's direction does not have as much value as the magnitude and phase of the current.

## 3.0 APPROACH

To perform advanced visualization decisions had to be made regarding hardware and software. The authors were fortunate to have access to a Silicon Graphics Incorporated (SGI) 4D/320GTXB. The SGI 4D/320GTXB is one of the SGI POWER Series™ line of computers. It can be configured with up to eight CPUs; the one used for this project has two 33MHz CPUs. It has the following performance ratings (SGI, 1991): 59 MIPs (VAX Dhrystone MIPS), 20 MFLOPS (DP Linpack 1000x1000), 41 SPECmarks. The GTXB has 48 bits color and 24 bits Z buffer. Its graphics performance is rated as 400K Vectors/sec, 150K Triangles/sec, and 100K Polygons/sec. The system used for this effort is configured with 64MB memory and a 19 inch console monitor.

Several graphics software packages were available on this SGI workstation, including PV-Wave, apE, Explorer and the SGI GL (Graphics Library). The available high level languages included C and Fortran. The Graphics Library (GL) provided the greatest flexibility in the development of the required visualization techniques. GL is a set of graphics and utility routines that provide high- and low-level support for graphics. The routines can be called from either C code or Fortran code. GL is quite primitive and yet allows one to access all the

powerful visualization capabilities of the SGIs including 3D drawing, Gouraud shading, device polling, double buffering, coordinate transformations, hidden surface removal (z-buffering), lighting, pick correlation, and texturing, depending on the hardware's capabilities. SGI provides an enormous number of demo programs that can be easily modified. GL provides a straightforward approach to developing the proposed visualization tools.

The NEC-MoM input data set is created by a program called NEEDS (Li, et al., 1988). The data set is an ASCII file in which each line represents a "card". The first two characters on each line refer to an alphabetic code that determines what the data on that line represents. For example, "CM" is a comment line and "GW" is a wire description line. The output from NEC-MoM is an enormous ASCII text file in a format that is very difficult to read from within another computer program. For that reason a parser program is needed to extract the data of interest and put it in a software readable format. A preprocessing filtering program, *filter*, was written in Fortran to put the input and output data in a form that would allow easy display of the data of interest.

## 4.0 VISUALIZATION PROGRAM STRUCTURE

The visualization programs were written in the ANSI C language using the SGI Graphics Library (GL) to access the visualization tools. The program to visualize the problem definition and solution description is named *view_nec*. The program evolved as feedback was received from users. However, the basic structure using multiple windows, pull-down menus, and transformations was determined from the beginning.

### 4.1 Windows

The beauty of working in an X-windows type environment, such as that on the SGI machines, is the flexibility it affords the user. That flexibility was retained in the development of *view_nec*. Each data component is displayed using 3D imagery in its own window. At any given moment during the running of the program the user has complete control over how many data windows are displayed as well as their sizes and locations. In addition, multiple copies of *view_nec* can be launched to do side by side comparisons of different NEC-MoM runs.

### 4.2 Menus

Pressing the right mouse button while the mouse cursor is within any *view_nec* window brings up a "pull-down" menu. This pull-down menu allows the user to select which data windows to open/close, which transformation is active, and whether a coordinate axis is displayed. Once a selection has been made, the affected windows are updated.

### 4.3 Transformations

The available transformations include rotation, translation, and zooming. Each 3D transformation is represented internally in the workstation by a 4 x 4 matrix. The IRIS Geometry Engines transform all geometric data (vertices of points, lines, and polygons) by multiplying each vertex by the accumulated matrices. In *view_nec* the transformations are actuated with the left mouse button held down and the cursor dragged across the screen.

There are three basic classes of transformations that can be carried out by the Graphics Library: projection transformations, viewing transformations, and modeling transformations. A good analogy is to a camera with a versatile lens. Projection transformations describe the type of lens on the camera. Viewing transformations determine where the camera is positioned and in

which direction it is pointed. Finally, modeling transformations affect the location, orientation, and size of the 3D geometric models in the scene.

There is often more than one way to carry out a transformation of a scene. For instance, instead of moving the camera toward the object, the object could be moved closer to the camera. However, there may be subtle differences. The transformation methods used in *view_nec* were chosen by selecting demo programs that gave the desired effect.

The zoom feature allows the user to expand a selected portion of the model for more detailed display. Zooming is achieved internally by using a projection transformation. The field of view in the y dimension is modified. This has the effect of making the scene appear closer or farther away. The aspect ratio between the field of view in x and the field of view in y, and the distances to the near and far clipping planes are kept constant.

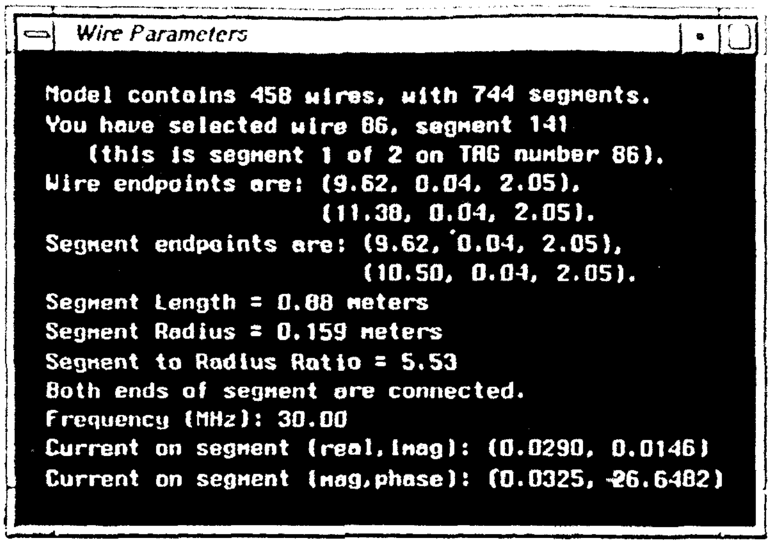
The rotate feature allows the user to rapidly change the orientation of the model. This permits a better feeling for the three dimensional nature of the model and often allows various features of the data to become more apparent. Rotation of the scene is carried out internally using a viewing transformation to move the viewpoint. The distance from the origin is kept constant while the azimuthal angle in the x-y plane and the incidence angle in the y-z plane are modified. This is akin to moving the camera over a spherical surface surrounding the scene.

Translate allows the user to move the model up/down or left/right in the plane of the screen. This shifts the origin and is useful before zooming in on a selected portion of the model. Translation of the scene is carried out internally using a modeling transformation. The program is set up to only allow translation of the object in the plane of the screen. The size of the object is preserved.

### 4.4 Pick Correlation

It quickly became apparent that a method was needed to selectively choose a single element, such as a wire segment, from the 3D wire object display. This was needed for troubleshooting as well as linking the display back to the NEC-MoM input data set. The middle mouse button was chosen for this purpose. The technique used is known as *pick correlation*. The Graphics Library provides this capability.

Pick correlation identifies objects on the screen that appear near the mouse cursor. Information about these objects is stored in a buffer. *view_nec* uses this information to allow the user to select a single wire segment from the object displayed and list all information about it. A sample wire parameters window is shown below.




Wire Parameters Window

## 5.0 VISUALIZATION OF METHOD OF MOMENTS

### 5.1 Problem Definition

The NEC-MoM input file describes the modeled object (such as a ship) as a collection of wires. At this time *view_nec* does not recognize patches. The description of each wire includes: a tag number (for identification purposes), the number of segments on the wire, the (x,y,z) coordinates for both the beginning and end points, and the radius of the wire. Some wires are tapered and so extra information is given for these wires to describe the tapering.

There are four windows that can be opened up to display the model's input geometry. The windows each display one of the following: Wire Segmentation (segment length in meters), Wire Radius (in meters), Segment to Radius Ratio, or Wire Connectivity (none, one, or both ends connected). All of these windows display the model as a 3D wire object. The data is encoded in the color of each wire segment using a linear or logarithmic color assignment scheme. A color key is displayed in the lower left corner of the window.

### 5.2 Computation Visualization

There has been some speculation that visualizing the method of moments matrix that has been extracted from NEC-MoM might give some insight into the validity of the wire model being used. A Graphics Library program, *view_mom*, was developed to allow display of almost any size method of moments matrix. Its structure is similar to that of *view_nec*, but it is quite a bit simpler.

*view_mom* allows the user to bring up two different windows. The first window has the data displayed as a 3D surface with the vertical offset and color proportional to the logarithm of the magnitude of the data. The second window is similar except it has the color proportional to the phase of the data. Each window allows the surface to be rotated, translated, and zoomed just as in *view_nec*. The right mouse button brings up the menu. The left mouse button performs the transformations. The middle mouse button performs a pick correlation that allows the user to select a point on the matrix. After a matrix point has been picked an information window

appears in the lower left corner of the console screen. This information window describes the matrix and gives information about the selected point. Included in this information are the row and column number of the point.

### 5.3 Solution Description Visualization

Many different solution description products are available for display. The visualization products include currents and charges on the wires (real component, imaginary component, magnitude, or phase), total near field, z-component of near field, theta component of far field, and phi component of far field.

#### 5.3.1 Currents and Charges

Currents and charges on the wires are displayed using the same technique as was used for the geometry description products: current and charge are color coded on a 3D wire display of the model. Again, both linear and logarithmic color codes are available. Since currents and charges are complex, each has four different data windows that can be displayed: real component, imaginary component, magnitude, and phase. Most users have found the magnitude window to be most useful.

#### 5.3.2 Near Fields

NEC-MoM allows the user to calculate the near field at selected locations around the model. These locations are usually defined by a 3D grid surrounding the model. The near field is a complex vector. Of most interest is the z-component since this will be the component that is most closely associated with hazards.

Several techniques were evaluated for displaying the near field data points. The most popular was the "fog" technique. *view_nec* displays near fields using a "fog" technique in which the density of activated pixels in the image is linearly proportional to the field intensity at the nearest calculation point. Since the calculation points usually form a 3D grid the image contains square blocks of fog varying in density with the field intensity. The fog is also color coded in a manner similar to that used for the geometry description products. The 3D wire model is drawn using a dark gray color so as not to detract from the near field display.

The near field windows have a thresholding capability. By clicking in the window with the middle mouse button the user is able to selectively change the threshold at which the fields are displayed. This allows the user to quickly determine what areas surrounding the model have fields above a particular cutoff level. The user can select any of the color key bin levels, HERP (Hazardous Electromagnetic Radiation for Personnel), or HERO (Hazardous Electromagnetic Radiation for Ordnance) for the threshold. HERP and HERO are functions of the radiation frequency. The near field windows display the value of this frequency.

#### 5.3.3 Far Fields

There are two windows available for the display of far fields. These windows allow the user to display either the theta component or the phi component of the far electric field. The far field is complex data. This makes display of it somewhat complicated. A method of displaying both the magnitude and phase simultaneously was sought. The selected method involves displaying the fields as a three-dimensional surface. The distance from a point on the surface to the origin is proportional to the field magnitude at that point. The color at the point is determined by the phase of the field at that point. Gouraud shading is used between points to transition the color.

## 6.0 OBSERVATIONS

During this project the authors learned a great deal about visualization techniques and limitations. One observation is that as more and more features are added to a piece of software, the user interface becomes the limiting factor in the utility of the program. Present efforts are directed toward providing a graphical user interface into *view_nec* and *view_mom*. Another observation is of the limits of hard copy devices such as the color printer that was attached to the SGI. Although it was a very high quality printer, it was extremely limited in its ability to faithfully reproduce the hue, saturation, and brightness displayed on the console. Subtle differences in hue could not be discerned, and saturation variations were washed out. Finally, without viewing the actual SGI display it is difficult to provide an understanding of the power of the EM visualization on a SGI 4D workstation. However, video making capability is available with the SGI. This is the only way to properly demonstrate the utility of the visualization products that were developed.

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